Designing Methods

Reinforced Concrete Construction

VOL. I JULY, 1908 No. 3

BRIDGES AND CULVERTS

FOR HIGHWAY TRAFFIC

FLAT SLAB AND GIRDER TYPE

Discussion of the special problems met with in the design of highway bridges and culverts.

Detailed design of flat slab bridge, box culvert and girder bridge, illustrating the application of the methods suggested.

THE AUGUST BULLETIN WILL CONTAIN:

Standard Designs for Flat Slab Bridges, Box Culverts and Girder Bridges, for the three classifications by loadings, adopted.

EXPANDED METAL AND CORRUGATED BAR CO.

Suite 925 to 937, Frisco Building

SAINT LOUIS

REINFORCED CONCRETE BRIDGES.

Reinforced concrete is now largely used for the construction of bridges and culverts, and its popularity is well deserved. No other structural material possesses, to the same degree, those qualities of permanence and freedom from maintenance charges so desirable for public works. Of all engineering structures bridges are probably the most exposed to the action of the elements and receive the severest load treatment. It is essential, therefore, that bridges be designed with unusual care and that the materials used in the construction be carefully selected. Concrete gains strength with age and is not affected by atmospheric influences—a concrete bridge is stronger at the end of ten years than it was at the age of three months.

Wooden, as well as steel bridges, are subject to annual repairs and periodic renewals, while for concrete bridges the initial appropriation represents the entire outlay, present and future. And the cost of a reinforced concrete bridge is not prohibitive; in fact, the cost is but slightly in excess of that of timber construction and usually considerably less than that of steel. Sand and gravel (or crushed stone) may usually be obtained near the site and the construction may be done with local labor.

A reinforced concrete bridge may be designed with the same exactness as a steel or wooden structure.

Reinforced concrete is more reliable than plain concrete or masonry; the construction is lighter, requiring less extensive foundations.

Reinforced concrete is not affected by atmospheric or corrosive influences.

A reinforced concrete bridge is practically free from vibration.

In viaduct work, where steam or electric cars are to be carried, reinforced concrete should be used, as it practically eliminates all noise.

Local labor and materials may be used in the construction of a reinforced concrete bridge.

FLAT SLAB AND GIRDER BRIDGES.

A flat slab design will in general be found more desirable and economical for spans up to twenty feet; for longer spans a girder type bridge should be used. By a "girder bridge" is meant a comparatively thin reinforced concrete decking carried by girders extending from abutment to abutment; these girders should preferably be entirely below the decking. In some cases, however, the side girders may be carried up

above the slab to form the side rail. Girder bridges are economical under the usual conditions for spans of from eighteen to thirty-five feet; for longer spans an arch bridge will probably be more desirable. Girder bridges have been built for spans as great as sixty or seventy feet; these larger structures, however, should be specially designed, and we have made no attempt to include such unusual structures in the standard tables given in these bulletins.

CLASSIFICATION BY LOADINGS.

Highway bridges must be designed to safely carry the heaviest load likely to come upon them, and as this maximum load varies with the locality we have arbitrarily adopted three standard classifications by loadings, which should cover all usual conditions.

In short span bridges, such as we are now considering, the concentrated loads are the determining factors in the design—the uniformly distributed loads usually specified (100 to 150 pounds per square foot) causing smaller stresses.

Class No. 1—Light highway specification answering the purposes of ordinary county traffic where the heaviest load may be taken as a twelve-ton road roller. Uniformly distributed load, 100 pounds per square foot.

Class No. 2—Heavy highway specification, designed for localities where heavy road rollers, up to twenty tons, and electric cars of a maximum weight of forty tons must be provided for. Uniformly distributed load, 125 pounds per square foot.

Class No. 3—City highway specification, designed for heavy concentrated loads and large interurban cars. This classification should be adopted for all city work; the weight of the maximum car has been taken as sixty tons. Uniformly distributed load, 150 pounds per square foot.

LOAD DIAGRAMS.

The following diagrams represent the loadings adopted in the above classifications and used in the design of the culverts and bridges shown in this bulletin:

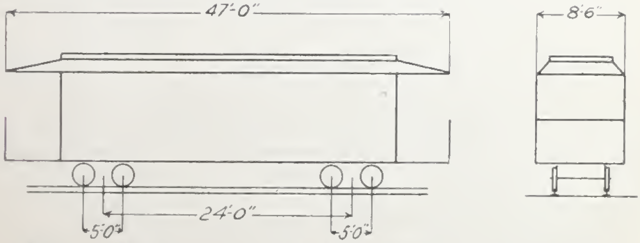


Fig. 1. Standard Car, Class No. 2—40 tons on eight wheels.

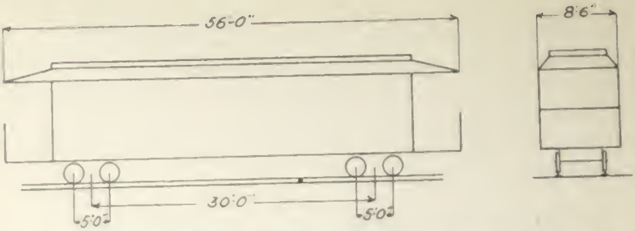


Fig. 2. Standard Car, Class No. 3—60 tons on eight wheels.

The concentrations due to a steam roller will be taken as indicated by Figure 3; two-thirds of the total load being assumed on the rear wheels.

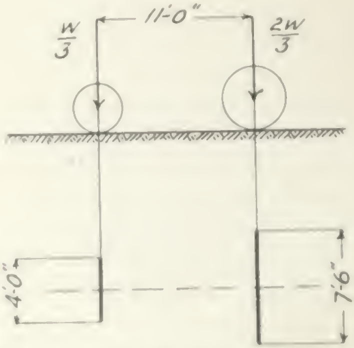


Fig. 3. Road Roller Loading Diagram, Class 2.

NOTE—Reinforced concrete slab bridges are very stiff and that part of the slab directly under the concentrated load is materially assisted by the adjoining sections. To assist this lateral distribution of load transverse reinforcement should be used in all slab bridges.

Earth Fill—When there is an earth fill over the culvert or bridge it acts to distribute concentrated loads and our methods of dealing with such conditions will be briefly outlined.

DEAD LOAD.

The dead load includes the weight of the bridge or culvert top, and the weight of that part of the fill supported by the bridge including the paving or track system. In all our designs the culvert will be considered as supporting a volume of fill as indicated in Figure 4.

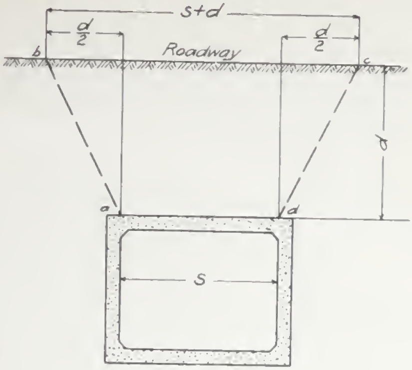


Fig. 4.

The trapezoid abcd represents the amount of fill considered as supported by the culvert; assuming the weight of the fill to be 100 pounds per cubic foot we may write

$$D_t = 100d\left(\frac{2s+d}{2}\right) = 50d(2s+d)$$

where D_t=load on 12″ length of culvert due to fill. D_t will be considered as a uniformly distributed load across the culvert.

To obtain the total dead load add the weight of a 12″ strip of culvert top, also the weight of paving or track system.

LIVE LOADS.

A uniformly distributed load shall be considered as causing the specified pressure per square foot on the bridge regardless of depth of fill.

A minimum fill of twelve inches is required on all bridges.

Wheel or road roller concentrations shall be considered as acting on a line whose length equals the out to out tread of the wheels.

Loads on car tracks shall be considered as uniformly distributed over a width of roadway equal to the length of the ties and in the direction of the track for a distance of two feet on both sides of single wheels and for a distance of the wheel base plus two feet for trucks.

The above distribution of load is at the level of the roadway. The following methods of finding the loads on the bridge itself are suggested:

Wheel Loads on Roadway—Assume distribution of load by fill to be only in the direction of the roadway and to be carried down on a slope of ½ to 1. The following diagram, Figure 5, showing the distribution of road roller concentrations, illustrates our method.

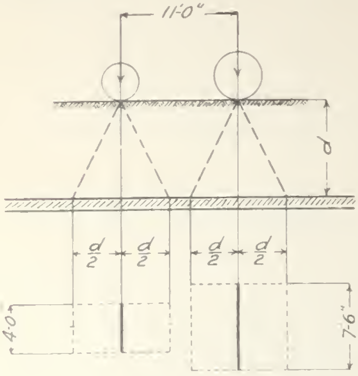


Fig. 5. Showing Distribution of Loads due to Road Roller.

With this arbitrary distribution of loading it will be noted that for a strip, the width of the front wheel, the loaded areas overlap when the depth of fill is greater than the distance between axles. In this case, consider the load as uniformly distributed over an area of slab 7'6" wide by $(d+11'0")$ long.

Wheel Loads on Tracks—See distribution by track system, page 81. These loads will be considered as distributed in a manner similar to that adopted for wheel loads on the roadway, excepting that the distribution will be assumed to be in both directions. It should, however, be borne in mind that on double track slab bridges the width of slab considered as supporting one track can not be taken as greater than the distance c. to c. of tracks.

Impact—When the fill is less than five feet add 25% for impact for rapidly moving loads.

The following diagram (Fig. 6) shows the assumed distribution of standard truck load, forty-ton car.

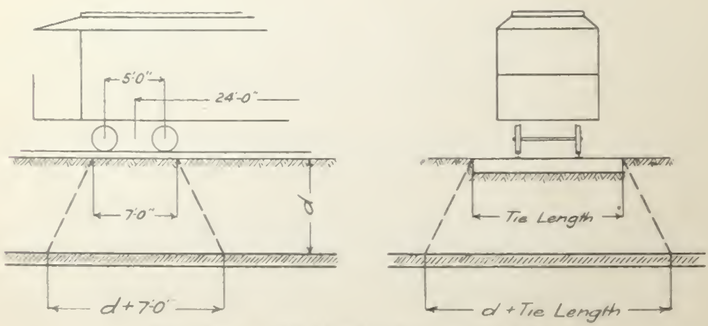


Figure 6. Load Distribution, 40-ton Car.

Treatment of Loads for Girder Bridges—The distribution of loads through the fill will be as above outlined; in this type of bridge, however, the girders must be so located as to properly take care of the track loads. The girders under the tracks being assumed to carry the full load.

Abutments and Side Walls—For the design of abutments and side walls take the horizontal component of the earth pressure as one-third of the vertical pressure at that depth, assuming the resultant to act at a distance one-third the height above the base. The intensity of the horizontal pressure due to live load may also be taken equal to one-third of the vertical intensity at any depth; assuming that the planes of zero pressure, bounding the supporting prism of earth to have a slope of one-half to one.

Weights and Dimensions of Electric Cars—The weights assumed for the electric cars in the preceding classification may seem rather large, but it should be remembered that the stresses in the bridge depend not only on the weight of the car, but also on the wheel base, distance between trucks, etc. The dimensions vary with the locality and the weights and dimensions chosen are, in our opinion, justified.

If it is desired to make a special design the following data on electric cars may be of use. The values given must be taken as approximate averages. The weights given are for the loaded car and include the weight of the trucks.

Small cars, such as are used in small towns, four wheels on two axles, seating twenty-eight persons. Car body, 20′0″x8′3″; over all length, 29′0″; distance c. to c. axles, 8′0″; weight, 11 tons.

City car for heavy service, seating fifty-two persons. Car body, 34′0″x8′6″; over all length, 47′0″; wheel base, 4′0″ to 6′0″; c. to c. trucks, 24′0″; weight, 15 tons.

Large interurban cars, seating 72 persons. Car body, 50′0″x8′6″; over all length, 56′0″; wheel base, 6′3″; c. to c. trucks, 30′0″; weight, 42 tons.

METHODS OF DESIGN.

Having found the loads on the bridge by the methods above outlined, the bending moments and shears are obtained by the ordinary principles of mechanics. All bridges of single span will be considered as beams freely supported at the ends and the bending moments must be figured on this assumption.

Box culverts, however, are reinforced against reverse moment at the ends and the designing moment may be taken as eight-tenths of that which would be developed in a simple beam.

All bridges and culverts will be designed on the basis of ultimate strength with a factor of safety of two on the dead and four on the live load, the minimum designing moment, however, to be taken as three times dead load plus live load moments. The elastic limit of the steel has been taken as 50,000 pounds.

The above method of designing gives a maximum working stress in the steel of about 16,500 pounds per square inch.

Since it is desirable to use local materials, and a dense hard aggregate may be difficult to obtain, the ultimate compressive strength of the concrete will be taken as 2,000 pounds per square inch. This compressive strength should be easily obtained with average aggregates using a 1:2:4 mix. The critical amount of reinforcement corresponding, using steel with an elastic limit of 50,000 pounds would be .0085 bd.

Girder Bridges—For single span bridges figure the inside girders as T-beams; in this case the cross section of the reinforcement should not exceed 2½% of the area of the rectangle enclosing the stem (bd). For bridges with two or more spans the girders should be figured as continuous rectangular beams and provision made for reverse moment over the supports.

Percentage of Reinforcement—Use .85% of reinforcement in slabs and rectangular beams for concrete of 2,000 pounds compressive strength. In T-beam designs limit the amount of reinforcement to 2½% of bd. These figures are based on the use of mechanical bond bars with an elastic limit of 50,000 pounds per square inch.

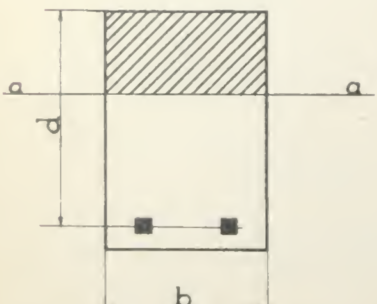


Figure 7. Rectangular Beam.

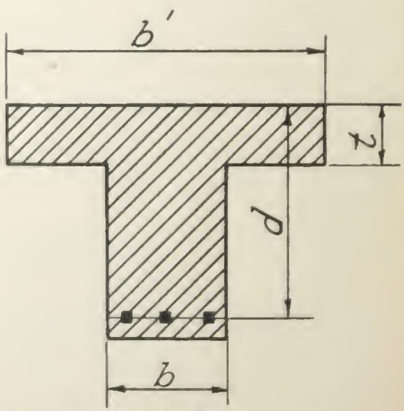


Figure 8. T-Beam.

FORMULAE TO BE USED IN DESIGNING.

Let M=moment of resistance of section in inch lbs.

M_o=ultimate moment of resistance of section in inch lbs.

q=area of reinforcement.

p=percentage of steel=$q \div bd$.

F=elastic limit of steel=50,000 lbs.

All dimensions as shown, in inches, and stresses in lbs. per sq. in.

Then we have for rectangular beams:

$$M_o = 370\ bd^2 \text{ for } q = .0085\ bd.$$

and for T-beams:

$$M_o = .86\ Fp\ bd^2 = .86 \times 50{,}000 \times p\ bd^2.$$

$$= 43{,}000\ p\ bd^2,$$ using high elastic limit corrugated bars.

(For complete discussion of these formulae, see May and June bulletins.)

WORKING STRESSES.

If it is desired to design for working stresses in the steel, use the formula:

$M = sq \times .86\ d$, where s=unit stress in the steel.

Shearing Provisions—In flat slab bridges it will not be necessary to make other provision for shearing stresses than by bending up part of the main reinforcing bars as required.

In girder bridges, however, special provision must be made against failure by diagonal tensile stresses, as the girders carry all the shear. The concrete may be assumed to carry safely fifty pounds of vertical shear per square inch of cross section (bd). In girders some of the reinforcing bars should be bent up near the ends of the beam and stirrups put in as required.

In all T-beam designs it is especially necessary to have a number of stirrups for the purpose of bonding the flange and stem.

BRIEF SPECIFICATIONS FOR MATERIALS AND LABOR.

Cement—Only *Portland* cement conforming to the requirements of the specifications adopted by the *American Society for Testing Materials*, June 14, 1904, shall be used.

Sand—Sand to be clean and coarse, and free from organic matter; a graded sand, with coarse grains predominating, is to be preferred.

Coarse Aggregate—Broken stone to be hard, durable limestone, or its equivalent, free from dust and foreign materials; maximum-sized particles to pass through a one-inch ring; fines to be removed by passing over a one-quarter inch screen. The fines may replace part of the sand. Under special conditions making for uniformity crusher run may be used, but this is not desirable.

Gravel shall be clean and of graded sizes, the sand content to be removed by screening as for broken stone.

PROPORTIONS OF MIX.

Concrete for columns, beams and slabs to be mixed in the proportion of one part cement to six parts aggregate; proportions by volume taking one bag containing not less than 94 pounds of cement, equal to one cubic foot of cement.

The proportions of fine and coarse aggregate used shall be chosen so as to give a concrete of maximum density; in no case, however, may the amount of fine aggregate be less than 40 per cent of the coarse.

REINFORCING STEEL.

All reinforcing steel used in bridge and culvert construction shall be rolled in such form that it has a positive mechanical bond with the concrete. Adhesive bond will not be considered sufficiently reliable for this class of structures.

Steel may be made by either the Bessemer or open-hearth process; bars to be rolled from billet stock. Re-rolled material will be accepted under conditions insuring rigid inspection.

The elastic limit and percentage of elongation shall be determined by tests on accurately-machined specimens and shall conform to the following requirements:

Elastic limit to be from 50,000 to 60,000 pounds per sq. inch; ultimate strength not less than 1 1/2 elastic limit.

The percentage of elongation in 8″ must not be less than given by the formula:

$$\text{Percentage of elongation} = \frac{1{,}400{,}000}{\text{Ult. Strength}} - 5.0.$$

Bending Test—Bars as rolled shall bend cold, 90 degrees, to a radius=three times the least diameter of the specimen, without sign of fracture.

Forms—Forms must be smooth and true to dimensions, with close joints to prevent leakage, and must be of sufficient strength to carry the load without appreciable deflection.

Removal of Forms—The time of removal of forms should be left to the discretion of the engineer, as the time required for the concrete to gain sufficient strength is dependent upon temperature and weather conditions and on the particular cement used. Forms for slabs should not be removed in less than two weeks under the most favorable conditions; girder forms should not be removed in less than three weeks.

Mixing—Machine mixing is to be preferred in all cases—hand mixing to be allowed at the discretion of the engineer. Concrete for reinforced work shall be mixed wet, sufficient water being used to make a mass that will flow readily and be of such consistency that the reinforcing steel will become coated with a protective coat of fluid mortar. Excess of water should be avoided, as it tends to a separation of the parts.

Placing—In girder bridges and in all T-beam designs the concrete must be placed the full depth (to the top of the slab) at one operation. If possible the work should be carried on continuously to completion.

DETAILED DESIGN OF A FLAT SLAB BRIDGE.

The following example illustrates the application of the methods above outlined:

Problem—Design a flat slab bridge, resting on abutments, clear span 16'0", with an earth fill 2'0" deep. Roadway to be 16'0" wide in the clear. Class 2 loading. See Fig. 9.

Figure 9.

In the design we will consider only a strip of bridge 12" wide as this simplifies matters. The section will be made constant across the width.

DEAD LOAD.

Weight of fill=100×2×(16+2)=100(36)=3,600 lbs.
Weight of slab (assuming thickness=16")=
$\frac{16}{12}$×150×16=3,200 "

Total . . . . 6,800 lbs.

Bending moment=$\frac{1}{8}$ WL=$\frac{1}{8}$×6,800×16
=13,600 ft. lbs.

Actual dead load moment=163,200 inch lbs.

LIVE LOADS.

For this span maximum stresses will be caused by the concentrated loads; the uniform load will not be considered. We will determine the bending moments due to the twenty-ton roller and to the forty-ton car, using the larger in the design.

Road Roller—Maximum moment occurs with rear wheels at center of span. Load on rear wheels equals two-thirds of 40,000 pounds=26,700 pounds. This load as previously explained (see page 82) acts on a line 7′6″ long; the distribution on the slab is shown by the following diagram (Fig. 10); the broken lines indicate the area of slab over which the load is distributed.

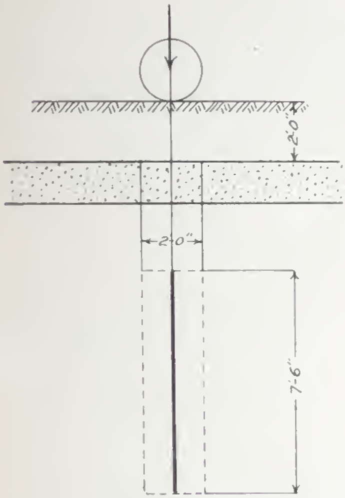


Figure 10.

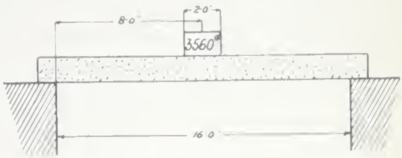


Figure 11.

The load per square foot on area $2'0'' \times 7'6'' = \frac{27,600}{2 \times 7.5} = 1,780$ lbs.

On a strip of bridge 12″ wide, the load would be as shown by Figure 11.

Maximum moment at center of span, on strip 12″ wide,

$$= M = (1,780 \times 8) - (1,780 \times \tfrac{1}{2}) = 13,400 \text{ ft. lbs.}$$

$$= 161,000 \text{ inch lbs.}$$

Electric Car—The maximum moment occurs with one truck on center of span. Distribution of load on slab is as shown by diagram (Fig. 12), assuming ties to be eight feet long.

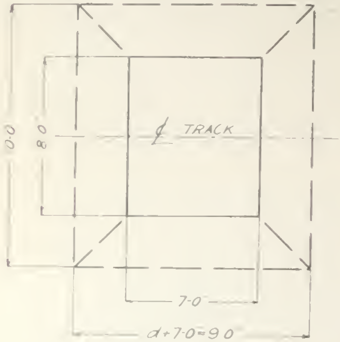


Figure 12.

The full line shows area over which truck load is distributed by track system; the broken lines indicate loaded area of slab.

Load per square foot of loaded area $=40,000 \div 90=445$ lbs.

The load on a strip 12" wide would be as shown by the following diagram, Fig. 13:

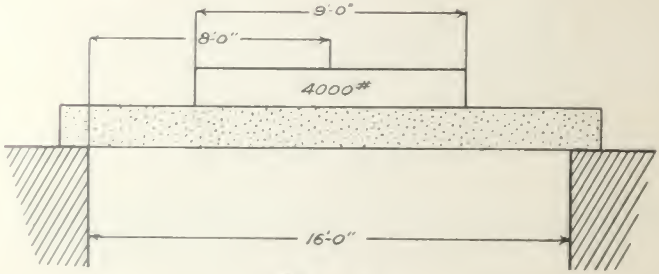


Figure 13.

Moment at center $=M=(2,000 \times 8)-(2,000 \times 2\frac{1}{4})=$ 11,500 ft. lbs.
$=138,000$ in. lbs.

Adding 25% for impact, moment $=172,000$ in. pounds.

This moment is larger than that due to the road roller and we will use it in the design.

Using a factor of safety of two on the dead load and four on the live load we have

Ultimate moment, dead load $=2 \times 161,000=$ 322,000 in. lbs.
" " live " $=4 \times 172,000=$ 688,000 "

Designing moment $=M_o=1,010,000$ in. lbs.

We can determine the depth of slab and the amount of reinforcement required by the formula:

$$M_o=370\ bd^2, \text{ for } q=.0085\ bd.$$

$$M_o=1,010,000=370\times 12\times d^2.$$

from which $d=15''$

$$q=.0085\times 12\times 15=1.53 \text{ sq. in.}$$

d=distance from top of slab to the center of the reinforcing bars, we will add 1½″ of concrete, giving 1″on underside of bars.

Make slab 16½″ thick; 1″ corrugated rounds spaced 6″ centers. Bend up every third bar at the sixth point, say 2′6″ from the abutments.

Transverse Reinforcement—To properly distribute concentrated loads and to tie the bridge in the transverse direction ½″ corrugated rounds will be placed (over the main reinforcing bars) crosswise of the bridge, and 12″ on centers.

Shearing Investigation—The dead load shear on a strip 12″ wide is 3,400 pounds.

The maximum live load shear occurs when the rear wheels of the road roller are 12″ inside the abutment, and is equal to

$$\frac{3,560\times 15}{16}=3,340 \text{ lbs.}$$

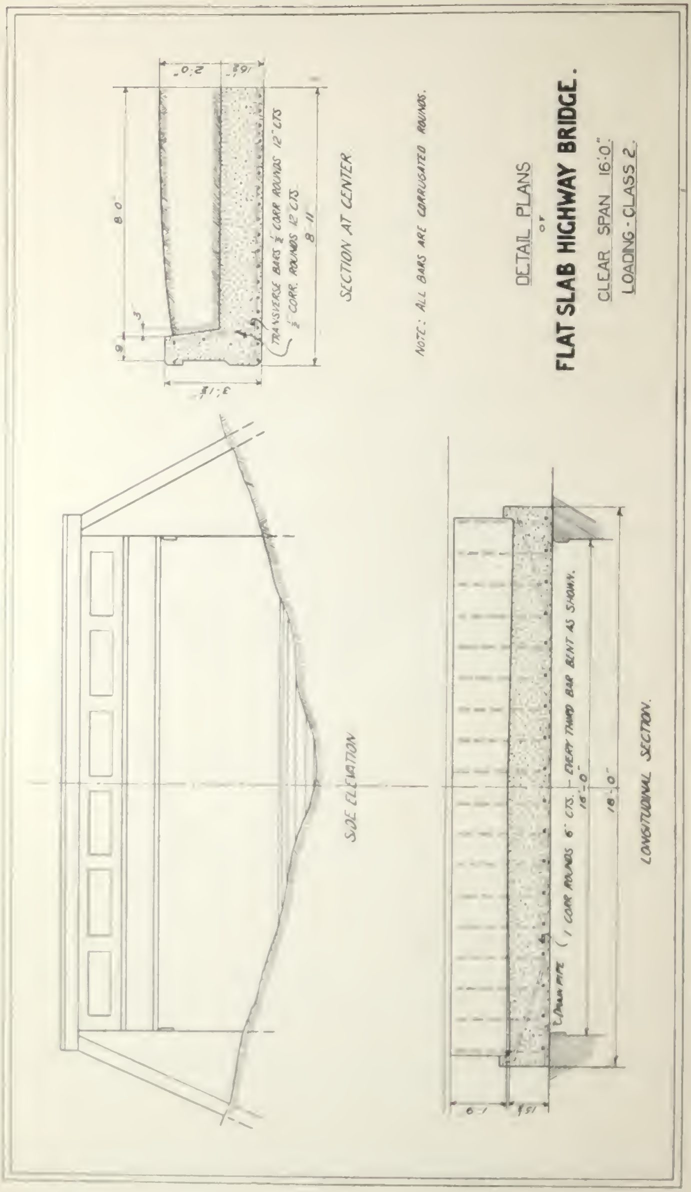
$$\text{Total shear}=3,400+3,340=6,740 \text{ lbs.}$$

At the allowed stress of fifty pounds the concrete alone is capable of carrying 12x15x50=9,000 pounds of vertical shear. This would indicate that no provision for shear need be made; every third bar will be bent up, however, as stated.

Side walls for retaining fill. It will not be necessary to figure these. They will be made 12″ thick and reinforced as shown.

Waterproofing—Some form of waterproofing should be used and the top surface of the slab arranged for drainage. The top surface of the slab will be as shown on the drawings.

Bearing on Abutments—All concrete bridges resting on abutments shall have at least 12″ bearing; a maximum pressure of fifty pounds per square inch will be allowed for slab bridges.


SECTION AT CENTER
TRANSVERSE BARS CORR ROUNDS 12" CTS
CORR. ROUNDS 12" CTS
NOTE: ALL BARS ARE CORRUGATED ROUNDS.
DETAIL PLANS OF
FLAT SLAB HIGHWAY BRIDGE.
CLEAR SPAN 16'0"
LOADING - CLASS 2.
SIDE ELEVATION
DRAIN PIPE
1 CORR ROUNDS 6" CTS. - EVERY THIRD BAR BENT AS SHOWN.
16'-0"
18'-0"
LONGITUDINAL SECTION.

BOX CULVERTS.

Box culverts will be built monolithic and reinforced against reverse moment at the corners. The methods suggested for designing this type of bridge will now be illustrated by a detailed design.

Problem—Conditions of span and loading as before, side walls to be eight feet high.

Design of Top Slab—The live and dead load moments will be figured as in the preceding example. For the designing moment, however, use eight-tenths of the moment that would be developed if the ends were free.

M_o, then$=\frac{8}{10}\times 1{,}010{,}000$ in. lbs.$=808{,}000$ in. lbs. (ult.)

Solving for d and q as before, we have

$$d=13.4'' \text{ and } q=1.36 \text{ sq. inches.}$$

Make slab 15″ deep and use 1″ corrugated rounds 7″ on centers.

Outside corner reinforcement use one-half the amount of steel required in slab and fillet the corners as indicated on drawings.

Bottom Slab—Make same as top slab.

As before transverse reinforcement will be required and bars will be introduced as indicated on the drawings.

SIDE WALLS.

In addition to supporting the top slab the side walls must be capable of resisting the horizontal pressure of the earth. This moment is of opposite sign to that produced in the side walls owing to the rigid connection with the top and bottom slabs. As before we will take the designing moment as eight-tenths of that which would be produced in a beam free at the ends.

The horizontal intensity of earth pressure will be taken as one-third of the vertical intensity. The horizontal pressure due to the live load will be based on a uniform load of 450 pounds per square foot on the roadway. This will give a horizontal pressure of 150 pounds per square foot, regardless of depth of fill, and should be ample to cover all contingencies

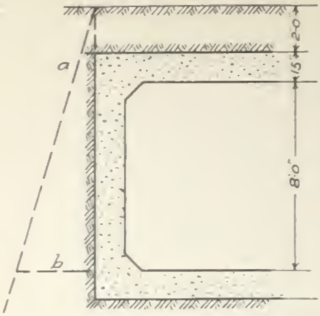


Figure 14.

The inclined broken line represents the intensity of the horizontal earth pressure at any point.

$$a=\frac{100\times 3.3}{3}=110 \text{ lbs.}$$

$$b=\frac{100\times 11.3}{3}=375 \text{ lbs.}$$

Average=242 lbs.

It will be sufficiently accurate to assume this average pressure as uniform over the side wall.

Average load per □′ then=242 lbs.+150 lbs.=392 lbs.

$M=\frac{1}{8}\,wl^2=\frac{1}{8}\times 392\times 8^2=3{,}130$ ft. lbs.

Using a factor of 3 on dead and live load, we have an ultimate moment of

$$3\times 3{,}130\times 12=112{,}500 \text{ inch lbs.}$$

Designing moment $=M_0=\frac{8}{10}\times 112{,}500=90{,}000$ in. lbs.

In all box culverts the side walls will be made the same thickness as the slab; d, then, would equal 13.4″.

The amount of reinforcement required would be

$$\frac{90{,}000}{808{,}000}\times 1.36=.15 \text{ square inch.}$$

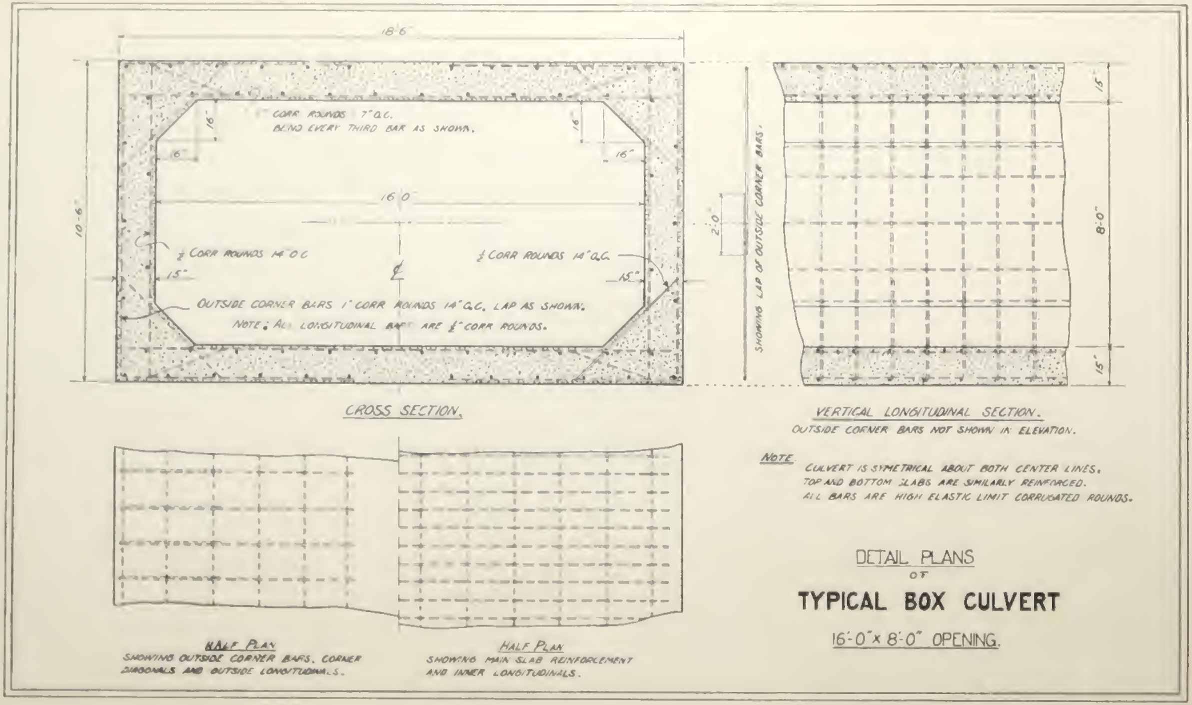
Use ½″ corrugated rounds, 14″ on centers.

The spacing of the reinforcing bars in the side walls should be a multiple of the spacing of the main reinforcing bars in the top slab, as this facilitates the placing of the steel.

NOTE—In the above design that part of the culvert directly below the roadway and for a distance of one-half d on either side, has been considered. Beyond these limits the stresses due to dead load decrease, the side slope usually being one and one-half to one. If desired the amount of reinforcement and thickness of concrete may be reduced toward the ends of the culvert

Longitudinal reinforcement should be used in all culvert construction. On account of unevenness in the supporting power of the earth and similar causes, box culverts often must act as beams spanning these weak places. Wing walls with large footings and slabs to prevent scour, when built monolithic with the culvert sometimes produce a bending moment in the whole structure, owing to the uneven soil pressure occurring under these conditions.

Aprons—Box culverts should be provided with aprons to prevent scour, and the wing walls should be figured as retaining walls.


18'-6"
10'-6"
16'-0"
1" CORR ROUNDS 7" O.C.
BEND EVERY THIRD BAR AS SHOWN.
16"
15"
½" CORR ROUNDS 14" O.C.
OUTSIDE CORNER BARS 1" CORR ROUNDS 14" O.C. LAP AS SHOWN.
NOTE: ALL LONGITUDINAL BARS ARE ½" CORR ROUNDS.
CROSS SECTION.
2'-0"
SHOWING LAP OF OUTSIDE CORNER BARS.
8'-0"
VERTICAL LONGITUDINAL SECTION.
OUTSIDE CORNER BARS NOT SHOWN IN ELEVATION.
HALF PLAN
SHOWING OUTSIDE CORNER BARS, CORNER DIAGONALS AND OUTSIDE LONGITUDINALS.
HALF PLAN
SHOWING MAIN SLAB REINFORCEMENT AND INNER LONGITUDINALS.
NOTE. CULVERT IS SYMETRICAL ABOUT BOTH CENTER LINES.
TOP AND BOTTOM SLABS ARE SIMILARLY REINFORCED.
ALL BARS ARE HIGH ELASTIC LIMIT CORRUGATED ROUNDS.
DETAIL PLANS
OF
TYPICAL BOX CULVERT
16'-0" x 8'-0" OPENING.

GIRDER BRIDGES.

The following detailed design will illustrate the application of the methods advocated to the design of a girder bridge:

Problem—Design a girder bridge, resting on abutments; clear span 32'0": earth fill 15" deep. Bridge to be 24'0" wide in the clear, with two 4'0" sidewalks and car track on center line. Class 2 loading.

The cross section of the bridge will be as shown on Fig. 15.

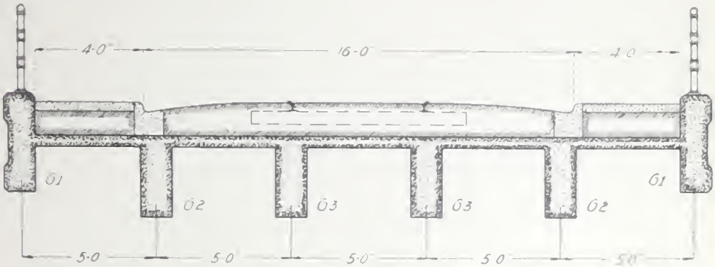


Fig. 15.

Floor Slab—The minimum thickness of floor slabs will be taken as 5". This thickness of slab should take care of extraordinary concentrated loads such as might be caused should a car be derailed on the bridge.

To provide for such contingencies all slabs for girder bridges will be designed for a live load of 500 pounds per square foot, in addition to weight of slab and fill, using a factor of two on the dead and four on the live load.

Moments will be figured by the formula $M=\frac{1}{12}wl^2$, since the slabs are continuous over three or more supports; l=distance c to c of beams.

DESIGN OF SLAB.

Dead load per square foot:

Slab, $\frac{5}{12}\times 150=$ 62 lbs.

Fill, $\frac{15}{12}\times 100=$125 "

Total, 187 lbs.

Dead load moment $= \frac{1}{12} wl^2 = \frac{1}{12} \times 187 \times 25 = 390$ ft. lbs.

Live load moment $= \frac{1}{12} \times 500 \times 25 = 1{,}040$ ft. lbs.

Designing moment $= M_o = (2 \times 12 \times 390) + (4 \times 12 \times 1{,}040) = 59{,}350$ in. lbs.

Taking a strip of slab 12" wide, we can find the thickness of slab and the amount of reinforcement required from the formula $M_c = 370\ bd^2$, in which $q = .0085\ bd$.

Inserting the values for M_o and b in this formula, we find that $d = 3.7$ inches, and $q = .38$ square inches, where q is the section of reinforcing steel required in a 12-inch width of slab.

Since we have made the thickness of the slab 5", d will be 4", which is greater than required by the formula. The amount of steel required may accordingly be decreased, and is equal to

$$\frac{3.7}{4} \times .38 \text{ sq. in.} = .35 \text{ sq. in.}$$

Slab will be 5" thick, reinforced with ½" corrugated rounds placed 7" on centers.

In the design we have considered the slab as partially fixed on the beams and to provide for the reverse bending moment developed, reinforcing bars will be placed in the top of the slab over the beams; the amount used will be one-half that required in the bottom of the slab and we will use ½" corrugated rounds 3'0" long, spaced 14" on centers.

NOTE—That part of the slab under the sidewalks will be the same as that under the roadway.

Girders—In all girder bridge designs the length center to center of bearings will be taken equal to the clear span plus one foot. This length, c. to c. of bearings, will be used in computing the stresses developed. It is desirable to have brackets at the ends of the girders when conditions permit, so as to reduce the unit vertical shearing stresses and gradually unload the reaction at the abutment into the girder. In all girder designs special provisions for taking care of shearing and diagonal tensile stresses should be made. Some of the main reinforcing bars should be bent up near the ends of the girder and stirrups used throughout the length.

Girder G1—This girder will be figured for the dead load and a live load of 125 pounds per square foot on the walk.

Dead load on girder:

Sidewalk,	$\frac{4}{12}\times 150\times 2\frac{1}{2}\times 32=$	4,000 lbs.
Fill,	$\frac{11}{12}\times 100\times 2\frac{1}{2}\times 32=$	7,350 "
Slab,	$\frac{5}{12}\times 150\times 2\frac{1}{2}\times 32=$	5,000 "
Girder (assumed $12''\times 36''$)	$=$	14,400 "
Total	............$=$	30,750 lbs.

Dead load moment$=\frac{1}{8}\ Wl=\frac{1}{8}\times 30{,}750\times 33=127{,}000$ ft. lbs.

Live load, 125 lbs. per square foot.

Live load on girder$=125\times 2\frac{1}{2}\times 33=10{,}000$ lbs.

Live load moment$=\frac{1}{8}\ Wl=\frac{1}{8}\times 10{,}000\times 33=41{,}200$ ft. lbs.

To get the designing moment, use a factor of 2 on dead load and 4 on live load, minimum to be, however, $3(d.\ l.+l.\ l.)$

$M_o=3(127{,}000+41{,}200)\times 12=6{,}050{,}000$ in. lbs.

Applying the formula $M_o=370\ bd^2$, and taking $b=12''$, we find that $d=37''$; $q=.0085\ bd=3.76$ square inches.

We will make girder 12″ wide and 40″ deep, using five 1″ corrugated rounds and bending up two bars as shown, at a point 4′0″ from each abutment.

Shearing Provisions—The maximum external vertical shear at the end of the girder, due to full live and dead loads equals 20,375 pounds.

In all girder designs the concrete will be assumed as capable of carrying 50 pounds of vertical shear over the cross section *bd*. Accordingly, if V_c=total shearing value of the concrete, we have:

$$V_c=12\times 37\times 50=22{,}200 \text{ lbs.}$$

This would indicate that no special shearing provisions are necessary. It is advisable, however, in all cases to make some shearing provisions, and we will use U-shaped stirrups of ½″ corrugated rounds, spaced 18″ throughout the length of the girder.

Girder G2—This will be designed for the average of the stresses in girders G1 and G3, so we will accordingly figure girder G3 first.

Girder G3—Class 2 loading requires that the design be based on the maximum stresses produced by either a twenty-ton road roller or a forty-ton electric car. (The alternative live load of 125 pounds per square foot causes much smaller stresses than the concentrated loads.)

The two girders G3 will be designed to carry the total car load.

Each girder may, however, carry two-thirds of the road roller concentrations; the full load on the front wheel and one-half of the load on the two rear wheels.

All interior girders on single span bridges should be figured as T-beams.

Dead load on girder:

$$\text{Fill, } \tfrac{15}{12}\times 100\times 5\times 32=20{,}000 \text{ lbs.}$$

$$\text{Slab, } \tfrac{5}{12}\times 150\times 5\times 32=10{,}000 \text{ ''}$$

$$\text{Girder (assume 450 lbs. per ft.)}=14{,}400 \text{ ''}$$

$$\text{Total}\ldots\ldots\ldots\ldots=44{,}400 \text{ ''}$$

Dead load bending moment:

$$M=\tfrac{1}{8}\,Wl=\tfrac{1}{8}\times 44{,}400\times 33=183{,}000 \text{ ft. lbs.}$$

Live Loads—Maximum moments due to *road roller*.

We will assume that only one road roller will be on the bridge at any one time. The maximum load on one girder then may be represented by two concentrated loads of 13,300 pounds each, 11′0″ on centers. The maximum moment will occur with one of the loads 2′9″ off center of span, as shown by Fig. 16.

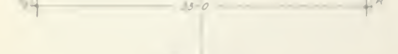


Fig. 16.

Since the fill is but 15″ deep, the effect of the fill in distributing the loads will be neglected in determining the moment on the girder.

$$R_1=\frac{13{,}300\times 8.25}{33}+\frac{13{,}300\times 19.25}{33}=11{,}100 \text{ lbs.}$$

$$M=13.75\times 11{,}100=153{,}000 \text{ ft. lbs.}$$

Maximum moment due to *electric car*.

For assumed distribution of load by track system, see Fig. 6, page 82.

The maximum moment will occur with one truck at the middle of the span, the other truck being off the bridge. (Two cars following each other will, for this span, produce practically the same moment as one car. See sketch of standard forty-ton car on page 79.)

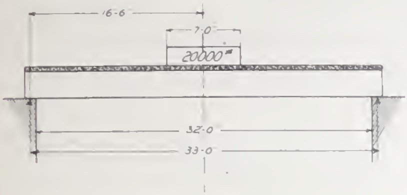


Fig. 17.

The loading for maximum moment will be as shown by Fig. 17; where the load given is that on one girder

$M=(10{,}000\times 16\frac{1}{2})-(10{,}000\times 1.75)=147{,}500$ ft. lbs.

To this static moment add 25% for impact for rapidly moving loads, giving a moment of 184,000 foot-pounds.

The maximum moment then due to the specified live loads is 184,000 foot-pounds.

Designing moment:

$$M_o=\Big((2\times 183{,}000)+(4\times 184{,}000)\Big)\,12=13{,}224{,}000 \text{ in. lbs.}$$

For the design of T-beams we will use the formula

$M_o=.86\ Fp\ bd^2=43{,}000\ p\ bd^2$, using high elastic limit corrugated bars. See page 85.

Assume $d=32''$ and $b=14''$, we then have

$$M_o=13{,}224{,}000=43{,}000\times 14\times 32^2\times p$$

from which $p=.0215$

$$q=.0215\times 14\times 32=9.65 \text{ square inches.}$$

We will make the girder 36″ deep over all and use eight $1\frac{1}{4}''$ corrugated rounds.

For this length of beam there is no danger of failure by horizontal shear along the horizontal or vertical planes of attachment of the stem to the flange. The distance between beams is 5′0″, and the amount of reinforcement used=.0215 bd, where b=14″; corresponding to an average percentage of reinforcement for the full width of slab of one-half of 1%. This indicates that there is ample width of slab between beams for T-beam action.

Shearing Provisions—The vertical external shear at the end of the beam due to dead load is 22,200 pounds, the load per foot of girder being 1,380 pounds.

The shear at the end of the girder due to the car would be practically a maximum when the center of one truck is 3'6" from the abutment; this total vertical shear may be taken equal to 20,000 pounds.

The total maximum shear at end of girder=42,200 pounds.

In providing for vertical shear we will assume that the concrete carries fifty pounds per square inch on the section bd, and put in steel to carry the excess.

Steel for reinforcing against diagonal tensile and shearing stresses will consist of bent up main reinforcing bars and loose stirrups.

Bent up bars will be figured to carry the diagonal component of the vertical shear in the "panel" in which they occur, the stress in diagonals not to exceed 12,000 pounds per square inch.

Loose vertical stirrups will be figured by the formula

$$s=\frac{.86\ d\ P}{V-(V_c+V_b)}$$

When s=spacing of stirrups required at any section,

P=total stress in one stirrup=total cross sectional area of the vertical legs of the stirrup times the allowed unit stress (16,000 lbs.).

V=external vertical shear at any section.

V_c=total vertical shearing stress that the concrete is assumed to be capable of taking=$v_c\times bd$.

V_b=amount of vertical shearing stress carried by bent up bars.

(For the derivation of this formula see page 13, May issue.)

Stirrups will be U-shaped and made of $\frac{5}{8}$" corrugated rounds, then

$$P=2\times.30\times16{,}000=9{,}600\ \text{lbs.}$$

$$V_c=50\times14\times32=22{,}400\ \text{lbs.}$$

ERRATA

IN THE

JULY BULLETIN

These pages are to take the place of the pages numbered 102, 103, 104 and 106 of the July number, which were printed in error.

INSERT BETWEEN PAGES 102
AND 103 OF JULY BULLETIN

Shearing Provisions—The vertical external shear at the end of the beam due to dead load is 22,200 pounds, the load per foot of girder being 1,380 pounds.

The shear at the end of the girder due to the car would be practically a maximum when the center of one truck is 3'6" from the abutment; this total vertical shear may be taken equal to 20,000 pounds.

The total maximum shear at end of girder=42,200 pounds.

In providing for vertical shear we will assume that the concrete carries fifty pounds per square inch on the section bd. and put in steel to carry the excess.

Steel for reinforcing against diagonal tensile and shearing stresses will consist of bent up main reinforcing bars and loose stirrups.

In the design we will neglect the effect of the bent up bars.

(If bent up bars are figured to carry the diagonal component of the vertical shear in the "panel" in which they occur, limit the direct tensile stress to 12,000 lbs. per sq. inch.)

Loose vertical stirrups will be figured by the formula

$$s=\frac{\frac{7}{8}\, d\, P}{V-V_c}=\frac{\frac{7}{8}\, d\, P}{V-50\times bd}$$

Where s=spacing of stirrups required at any section,

P=total stress in one stirrup=total cross sectional area of the vertical legs of the stirrup times the allowed unit stress (16,000 lbs.).

V=external vertical shear at any section.

V_c=total vertical shearing stress that the concrete is assumed to be capable of taking=$v_c\times bd$.

(For the derivation of this formula see page 63, May issue.)

If the stirrups are to be figured to carry all the vertical shear without assistance from the concrete, use the formula

$$s=\frac{\frac{7}{8}\, d\, P}{V}$$

Should it be desired to include that part of the vertical shear assumed to be carried by the bent up bars the formula becomes

$$y=\frac{.86\ d\ P}{V-(V_c+V_s)},\text{ in which}$$

V_s=amount of vertical shearing stress carried by bent up bars.

The following table gives the data necessary to determine the required stirrup spacing, neglecting the effect of the bent up bars:

Stirrups—U-Shaped, ½″ Corrugated Rounds, P=6,080.

Distance from Abutment.	Vert. Ext. Shear, V.	V_c	$V-V_c$	Required Spacing, y.
0	42,200	22,400	19,800	8.4″
2	38,400	22,400	16,000	10.4″
4	33,200	22,400	10,800	15.5″
6	28,400	22,400	6,000	27.9″
8	24,200	22,400	1,800	....
12	16,100	22,400	....	....

We will make spacing nine inches for a distance of six feet from the abutment, increasing the spacing to eighteen inches beyond this point.

Bent Up Bars—Bend up two reinforcing bars at a point 6′6″ from abutment, and two additional bars 3′3″ from abutment.

Girder G2—In designing this girder we will take the average of the moments in girders G1 and G3.

M_o, then=½(6,050,000+13,224,000)=9,637,000 in. lbs.

This girder will be made the same size as G3; the amount of reinforcing steel required may be determined by the formula

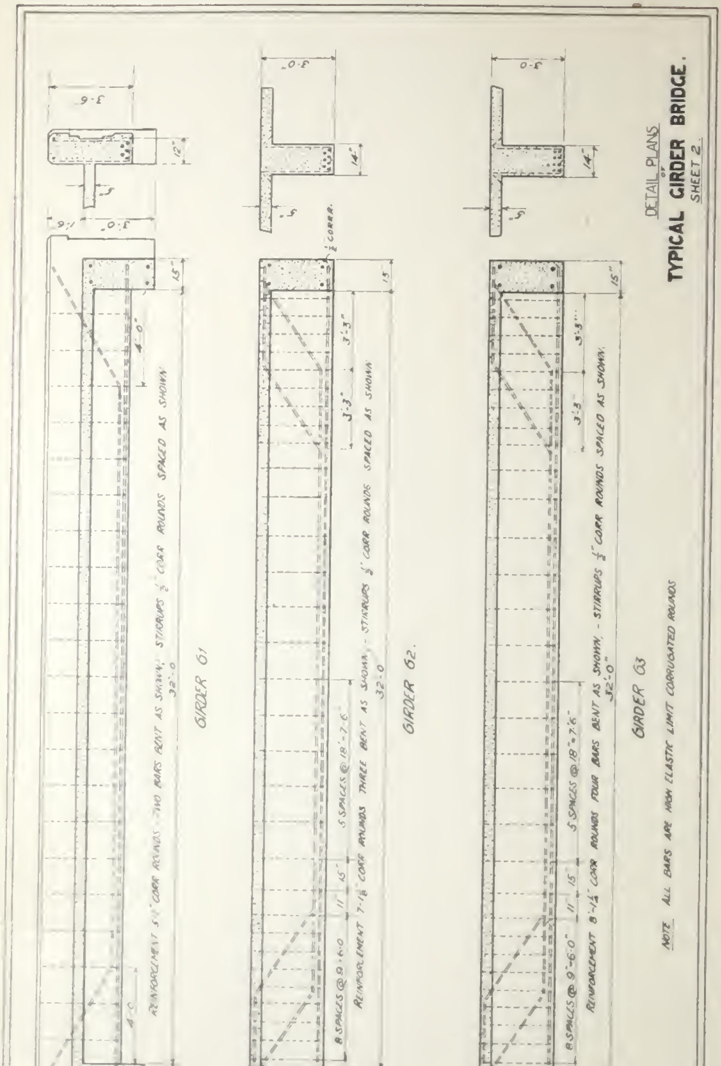
$$M_o=s\ q\times.86\times d$$

$$9{,}637{,}000=50{,}000\ q\times.86\times32$$

from which q=7.0 square inches.

Make girder 36″x14″ as before, using seven 1⅛″ corrugated rounds. Bend up one bar 6′6″ from end and two bars 3′3″ from abutment. Stirrups: use ½″ corrugated rounds same spacing as in G3.

Bearing of Bridge on Abutment—In order to properly distribute the load and provide for sufficient bearing area the bridge will be made solid for the full depth of the girders, where it rests on the abutment. This construction is desirable on all girder bridges, owing to the rigidity and general stiffness given by the solid end.


DETAIL PLANS
OF
TYPICAL GIRDER BRIDGE.
SHEET 2.
GIRDER G1
GIRDER G2.
GIRDER G3
32'-0"
NOTE ALL BARS ARE HIGH ELASTIC LIMIT CORRUGATED ROUNDS

We will bend up two reinforcing bars at a point 7′0″ from abutment, and two additional 3′6″ from abutment. For a distance then of 7′0″ from the abutment we would have two 1¼″ corrugated rounds, at a slope of 3 to 2, carrying their share of vertical shear (figuring same on a basis of a direct stress of 12,000 pounds per square inch) of 16,200 pounds. Beyond the 7′0″ point vertical stirrups must be provided to carry the excess shear.

The following table gives the values for the shear at various sections and data determining the stirrup spacing:

Stirrups—U-Shaped, ⅝″ Corrugated Rounds, P=9,600.

Distance from Abutment.	Vert. Ext. Shear $=V$.	V_c	V_s	$V-(V_c+V_s)$	Spacing $=y=\dfrac{0.86\ d\ P}{V-(V_c+V_s)}$
0	42,200 lbs.	22,400 lbs.	16,200 lbs.	3,600 lbs.	7.3″
2	38,440 lbs.	22,400 lbs.	16,200 lbs.	....	.....
4	33,200 lbs.	22,400 lbs.	16,200 lbs.	....	.....
6	28,400 lbs.	22,400 lbs.	16,200 lbs.	....	.....
7	26,200 lbs.	22,400 lbs.	0.00 lbs.	3,800 lbs.	7″
8	24,200 lbs.	22,400 lbs.	0.00 lbs.	1,800 lbs.	14.6″
12	16,100 lbs.	22,400 lbs.	0.00 lbs.	....	.....
16	10,000 lbs.	22,400 lbs.	0.00 lbs.	....	.....

This would indicate that with ⅝″ corrugated round stirrups, a spacing of 7″ is required at the end and at a point 7′0″ out from the abutment.

Space stirrups 7″ on centers for a distance of 8′0″, increasing spacing to 18″ at the 12′ point, and using this spacing to center of beam.

Girder G3—In designing this girder we will take the average of the moments in girders G1 and G3.

$$M_o, \text{ then} = \tfrac{1}{2}(6{,}050{,}000 + 13{,}224{,}000) = 9{,}637{,}000 \text{ in. lbs.}$$

This girder will be made the same size as G3; the amount of reinforcing steel required may be determined by the formula

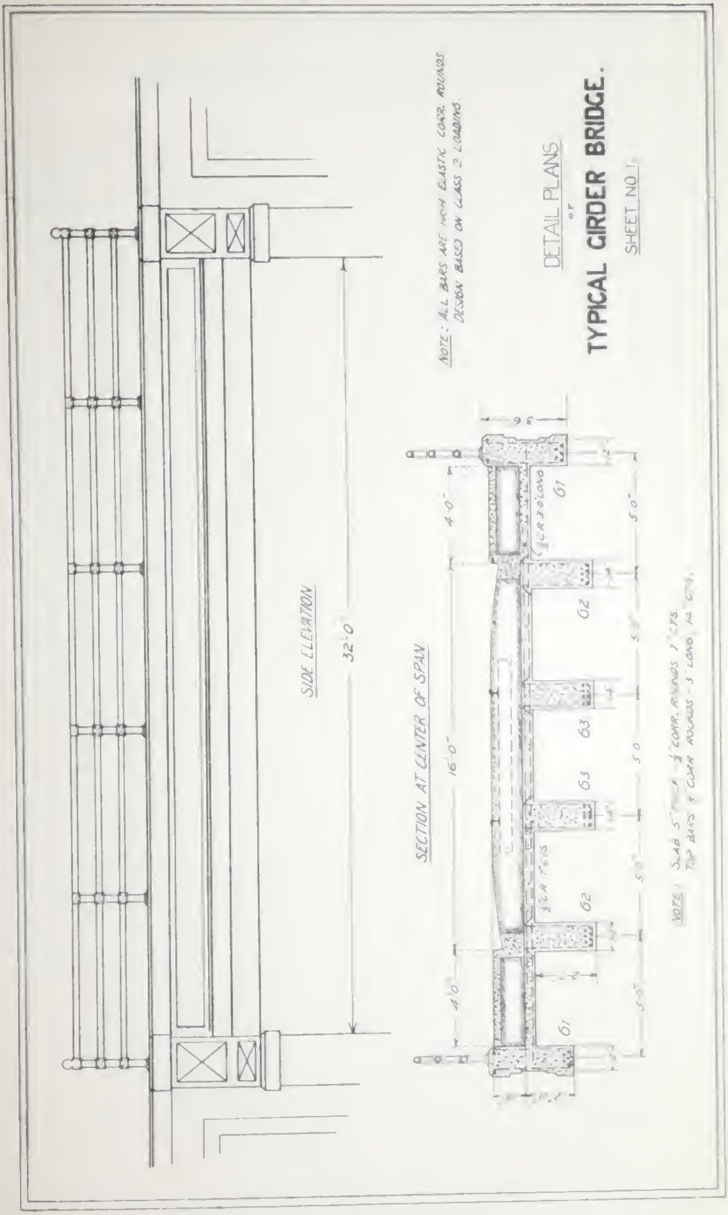
$$M_o = s\ q \times .86 \times d$$

$$9{,}637{,}000 = 50{,}000\ q \times .86 \times 32$$

from which q=7.0 square inches.

Make girder 36"x14" as before, using seven 1⅛" corrugated rounds. Bend up one bar 6'6" from end and two bars 3'3" from abutment. Stirrups: use ½" corrugated rounds same spacing as in G3.

Bearing of Bridge on Abutment—In order to properly distribute the load and provide for sufficient bearing area the bridge will be made solid for the full depth of the girders, where it rests on the abutment. This construction is desirable on all girder bridges, owing to the rigidity and general stiffness given by the solid end.


SIDE ELEVATION
32'-0"
SECTION AT CENTER OF SPAN.
4'-0"
16'-0"
4'-0"
G1
G2
G3
G3
G2
G1
5'-0"
NOTE: ALL BARS ARE HIGH ELASTIC CORR. ROUNDS
DESIGN BASED ON CLASS 2 LOADING.
DETAIL PLANS
OF
TYPICAL GIRDER BRIDGE.
SHEET NO 1.